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CALIFORNIA EXPERIENCE IN CORRECTION OF LANDSLIDES AND SLIPOUTS

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HIGHWAY DIVISION

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California Experience in Correction of Landslides and Slipouts

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Property damage, interruption and interference with transportation and communication, even loss of life --these are the consequences of landslides, phenomena which occur in almost all parts of the world. In California, with its wide variety of geologic, topographic and climatic conditions, landslides constitute a serious problem in highway design, construction and maintenance; correction treatment alone of landslides affecting State highways requires an annual expenditure of hundreds of thousands of dollars.

Corrective treatment of landslides cannot be intelligently designed without some knowledge of the types, causes and mechanics of landslides. Therefore, before describing in detail California experience in the correction of landslides and slipouts, the mechanics of landslides will be discussed briefly.

What is a landslide? Terzaghi's answer to this question is as follows:

> "The term landslide refers to a rapid displacement of a mass of rock, residual soil, or sediments adjoining a slope, in which the center of gravity of the moving mass advances in a downward and outward direction."[2]

Classification of Landslides

One particular type of landslide which is most troublesome to highway engineers is the slipout; this term refers to a landslide occurring at or below roadway grade, in which a portion or all of the roadbed moves downward and outward. Slipouts generally occur where the roadbed is partially on embankment; a typical slipout does not extend above the roadway grade; however, if the surface of rupture is deep the head of the slipout may be within the cut slope above the road.

There are many types of landslide which may be classifield according to rate of movement, type of soil, ground water and moisture conditions, geological structure and other variables. But regardless of the type of landslide the slide movement occurs when the driving force exceeds the resisting force. The driving force consists of gravitational (and perhaps seepage forces or hydrostatic pressure); the resistance to sliding is the shearing resistance of the soil mass. Prevention and correction of slides involve either reduction of the driving force or increasing the resisting force, or more often a combination of the two. These corrective measures can be accomplished by a number of different methods; this paper will discuss only those which have been applied by the Division of Highways in California.

A complete description of the causes and classification of landslides is

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1. Supervising Materials and Research Engineer, California Division of Highways, Materials and Research Department.
2. Mechanism of Landslides by Karl Terzaghi. The Geological Society of America--Engineering Geology (Berkey) Volume, November 1950.

beyond the scope of this paper, and such information can be found in the literature on landslides.[3] However, a brief mention will be made of some of the more common types of landslide encountered on California highways, as a particular slide must usually be analysed and classified as to type before corrective treatment can be undertaken.

The most common and at the same time the most troublesome one is the slump type of landslide, in which a large mass of soil moves, with relatively little deformation, along an internal slip surface or surface of rupture. The trace of the surface of rupture, on a vertical plane along the axis of the slide commonly, although not necessarily, approximates a circular arc. At the toe of the slump type slide there is often a push-up or up-heaval. Roadway slipouts are generally of the slump type slide. Groundwater is an important factor causing slump slides.

A second type, the rock slide, although fairly common and sometimes of considerable magnitude, is more readily recognized than most other types, and the causes are more apparent. The movement is frequently controlled by zones of weakness such as contact planes between weak strata or weak bedding planes. The general group of rock slides includes "bedding-plane" slides and slides of talus or detritus. Groundwater is seldom the prime cause of these movements. Numerous other types of landslide could be listed, but the first-mentioned slump type landslide includes the greatest number of slides to which corrective treatment has been applied in California.

Correction of Landslides

Investigation.

The first and very important step in the correction of a landslide is the exploration and analysis of the slide. Seldom can the most economical and successful treatment be determined from a superficial inspection of the slide. A contour map of the slide and adjacent terrain is most helpful in analyzing the problem; a geologic study should be made to determine the bedding, structure and nature of the rock. Borings are essential for locating the rupture surface, determining groundwater conditions and, where necessary, obtaining undisturbed soil samples for laboratory tests. With the information thus obtained the slide can be analyzed, the causes determined, and various kinds of corrective treatment compared in order to determine the most economical treatment which will provide reasonable assurance of stability. In most cases there are several possible alternate methods of correction, and the choice must be based on costs, with due consideration of the probable effectiveness of the several alternate treatments. In spite of all the studies and calculations the final design will necessarily be influenced by experience, judgment, and perhaps some intuition on the part of the soils engineer.

The preliminary investigation is essentially the same for both the roadway slipout and the slide above grade. Although the corrective treatment for the two may differ somewhat, the differences are not sufficient to warrant separate discussions in this brief paper. Rather, the various slide treatments with which California has had experience will be described, with comments on the applicability to the two types of land movement.

Importance of Drainage.

Frequent reference will be made to groundwater and subdrainage; before

3. See for example Landslides and Related Phenomena by C. F. Stewart Sharpe.

proceeding further with a discussion of slide treatment it seems pertinent to comment on the effect of groundwater, in order that the importance of drainage be clearly understood. The popular concept of moisture causing slides by lubrication of the soil is considered somewhat fallacious. Groundwater acts in two ways to induce slide movement; first, the weight of a soil mass increases appreciably as the soil becomes wet, thus adding to the driving force tending to cause movement; second, and of even greater importance, the presence of water results in a reduction in shear strength of the soil. If the soil is cohesionless, a rise in the water table results in a lowering of the effective soil weight, with a corresponding reduction in the available shearing strength; in the case of cohesive soils the cohesion decreases with increase in moisture content. If hydrostatic excess pressures develop, the normal forces contributing to the frictional resistance of the soil may become nil, and the soil then possesses little or no internal friction. In addition to these two factors groundwater movement may result in seepage forces within the soil mass, which adds further to the forces inducing slide movement. Water is undoubtedly the most important single factor contributing to slide movement!

Correction by Drainage Blanket.

Seepage may cause failures of cut slopes even though major landslides do not develop. A short time after construction of a project in Monterey County a small slide developed in one of the cut slopes, and soon progressed to the extent that a private road and gas line above the cut slope were jeopardized. Figure 1 shows a typical cross-section through this slide. The slide action appeared to be due to groundwater and seepage, and was successfully treated by placing a blanket of pervious material on the face of the cut and installing an underdrain along the gutter line, as shown in the sketch. This type of treatment, with various modifications, has been appled successfully in a number of cases where the slope failures were due to progressive weakening of the cut slope rather than true landslides in which large masses of soil had moved.

Change of Alignment to Avoid Slide Areas.

The most obvious, but sometimes overlooked, method of correcting a slide is to avoid it by a change of alignment of the highway. Occasionally, by a slight line change, the highway can be shifted into stable ground at slight cost and without worsening the alignment objectionably. Such a possibility, although occurring infrequently, should not be overlooked.

Correction of Slide by Grade Change.

There have been instances in California where, due to slide movement in adjacent cut slopes, the roadway pushed up, causing objectionable distortion and humps in the grade line. In at least two such cases it was feasible to raise the grade line through the slide area, and by the placement of about ten feet of embankment over the push-up areas the slides were stabilized, due to the added surcharge weight at the toe of the slide.

This type of corrective treatment is illustrated by Figure 2, which shows a typical cross-section through a roadway cut on a project in San Diego County, where a slide and push-up of the roadbed occurred during construction. After the slide area had been mapped and borings made, the slide was analyzed by application of conventional soil mechanics techniques. These studies indicated that the removal of any reasonable amount of slide material would not

effect the desired stability. However, by constructing a strut fill at the toe of the slide and removing a small amount of material near the head of the slide, the factor of safety would be increased from 0.8 to about 2.0. Accordingly, the roadway grade through the cut was raised about eight feet, and the material for constructing the embankment required by the higher grade line was obtained by benching the cut slope, all as depicted on Figure 2.

The majority of slides cannot be corrected by line or grade changes, and some means must be found to improve one of the two basic factors affecting stability, i.e. either by reducing the driving force or by increasing the shear resistance, or some combination.

Slump Type Landslide General Considerations.

In the slump type landslide, in which the cut slope or natural ground above the roadway is sliding onto or across the roadbed, two types of treatment have been used successfully in California: (1) reducing the driving forces by removing weight at the head of the slide, or by benching or flattening the slope; (2) subdrainage, either by horizontal drains or by drainage trenches. If the slide is shallow and the transverse slope relatively flat, the first method is often most economical. If the slide is large, and especially if the transverse slope of the terrain is steep, it is often uneconomical to remove sufficient material to stabilize the slide by this means alone; in such cases horizontal drains have proven most effective. Only in very shallow slides are drainage trenches normally feasible.

The unloading of a slide must be carefully planned, as removal of material from the wrong area may reduce the stability instead of improving it. It has been our experience that benches are essential, both to provide surface drainage and to intercept seepage which usually occurs in this type of slide; the benches also serve to prevent rocks or mud from falling on the traveled way. The design of the excavation slopes and location of benches are based on the data obtained in the preliminary investigation of the slide.

Correction by Horizontal Drains.

Increased incidence and severity of landslides were concomitants of the increasingly large cuts and fills necessitated by continuous improvements in the geometric standards of California highways. Realizing the importance of adequate subdrainage in the prevention and correction of landslides, California highway engineers attempted to devise more effective and economical methods of drainage. Although the idea of installing perforated drain pipe in drilled horizontal holes did not originate in this Department, the California Division of Highways pioneered in the development of practicable methods and equipment for installing horizontal drains. These methods, sometimes in modified form, have been used in recent years by several other States and Agencies. The first installation of horizontal drains by this Department was made in 1939, since which time an aggregate of about 200,000 lineal feet of drains have been installed at approximately 100 different slide locations in California. Although slide movement has continued at a few of these locations, the vast majority of the horizontal drain installations have effectively stabilized the slides or reduced the slide activity to a negligible amount. The largest single installation of horizontal drains by the California Division of Highways was at the Orinda slide in Contra Costa County, where about 12,000 lineal feet of drains were installed. A detailed description of this slide has already been published.[4]

4. "Orinda Slide" by E. W. Herlinger and Gifford Stafford, California Highways and Public Works, January-February 1952.

A typical example of slide correction by means of horizontal drains is a roadway cut in San Luis Obispo County, where a large slide occurred during construction. Figure 3 is a plan view and Figure 4 a typical cross-section of this slide, showing the horizontal drains installed. The water table dropped rapidly after the drains were installed, and no further slide movement has occurred.

When horizontal drains are to be installed, the slide is first resloped to improve surface runoff, and benches are constructed at proper levels from which to install the drains. Vertical exploratory borings are helpful in locating the water-bearing layers; these borings serve as a guide in fixing the location and gradient of the drains, and also provide observation wells for recording the effect of the drains on the groundwater level.

Use of Piles, Bulkheads and Retaining Walls.

A commonly suggested method of combating slide movement is the use of piles, bulkheads or retaining walls. It has been the experience of this Department that such treatment is successful only in exceptional cases; the forces involved in a large landslide are of such great magnitude that in most cases the added restraint furnished by piles or walls is insufficient to produce stability, and as a result the retaining structure is sheared or displaced. However, walls and bulkheads have been used successfully in certain cases where the slide was relatively shallow and the rate of movement slow. These walls act in two ways to stabilize slides: (1) they provide increased resistance against movement; (2) retaining walls or bulkheads, when backfilled with pervious material, provide drainage at the toe of the slide mass.

One useful application of the retaining wall is for controlling talus slides. Any excavation at the toe of a talus slide will induce movement which continues until the talus slope has reached its natural angle of repose. Movement at the toe can be prevented by retaining walls and the slope may thereby be stabilized. The forces exerted by the talus slide are slight compared to the slump type slide.

A few slides have been corrected by a modification of the retaining wall principle. Where the slip surface is above roadway level the usual retaining wall would sometimes be founded on questionable foundation, or if extended down to firm footing the height would be excessive. At one location where this condition existed a nominal height wall was constructed in the slope at the surface of rupture, with heavy reinforced concrete struts extending down the slope to a footing below roadway grade. To prevent uplift of the wall due to the thrust of the slide pressure cast-in-place concrete piles were used under and tied to the retaining wall. This type of slide treatment has limited application, but is cited as an example of devising special treatment to fit conditions at a particular slide.

Correction of Rock Slides.

You will note that most of the treatments discussed above refer to the slump type of landslide, which is the most troublesome and at the same time most difficult to analyze and correct. Rock slides, especially of the bedding-plane type, are common, but the choice of corrective treatment is rather limited. By means of a geologic study the rock formation, dip and strike, and competency are observed. After such information is obtained the corrective treatment can be designed; this usually consists of excavating sufficient material to prevent further slide movement along the bedding planes or zones of weakness within the rock formation.

All of the slide correction methods discussed thus far have been in connection with landslides in slopes above roadway grade. Although large volumes of earth are excavated annually from such slides and considerable money expended in their correction, roadway slipouts cause greater interference to the free movement of traffic and are often more costly and more difficult to correct. The very nature of a slipout prevents the application of some of the treatments used in stabilizing slides in roadway cuts: in the slipout the soil mass which comprises the driving weight consists of the embankment and roadbed, therefore, the removal of weight from the head of the slide is not feasible. The slipout may be corrected by three general methods; (1) drainage, by means of either horizontal drains or stabilization trenches; (2) construction of toe support or strut fills at the toe of the slipout; (3) increasing the shearing resistance by construction of buttresses at the toe. This latter method, although used to some extent in preventive treatment, has been applied infrequently to correct active slipouts.

A number of large slipouts have been correct by excavating a system of stabilization trenches placing filter material on the bottom and slopes of the trenches, and then restoring the embankment. A detailed description of one of the earlier applications of this method of slipout treatment was published in 1938.[5] This slipout was on a project near Trinidad, which was designed in 1935 and constructed in 1937. When this method is applied the stabilization trenches are excavated down to firm material below the slip surface, and thus contribute a considerable increment of shear strength in addition to providing subdrainage. If the slipout is small one such transverse trench may be sufficient; on the other hand, a large slipout may require an extensive system of drainage trenches; frequently a herringbone pattern of trenches is used. This method of slipout correction has been very successful; however, it is costly, and if the embankment is of great height and the slide is deep, the cost of correction by this method is sometimes prohibitive.

A large slipout on the Redwood Highway in Humboldt County was corrected by means of stabilization trenches. About two years after construction, a large embankment slipped out, necessitating construction of a detour to permit movement of traffic. Borings and geologic study showed that the slipout was caused by seepage forces in a mantle of disintegrated shale and sandstone which was underlain by firm sandstone . Various methods of correcting the slipout, including re-alignment of the road, were compared. The adopted treatment, which consisted of stabilization trenches, is depicted on Figure 5 and 6 showing a plan view and typical cross-section respectively.

Correction of Slipouts by Horizontal Drains.

Installation of horizontal drains is often the most economical method of correcting roadway slipouts. The drains are usually installed from the toe of the embankment, and if necessary from one or more benches on the fill slope. The location, number, length, and gradient of the drains are estimated from boring data, but are modified according to conditions observed during the progress of the work.

A slipout which occurred on the Redwood Highway in Humboldt County is a typical example of treatment by the installation of horizontal drains. The entire outer shoulder had slipped out, and there was serious settlement of one traffic lane. Borings revealed that groundwater was causing the slip-out,

5. "Problem of Slipouts Studies by State Highway Engineers" by A . W. Root, California Highways and Public Works, March 1938.

and study of the slide indicated that horizontal drains would be the most economical corrective treatment. Figure 7 is a plan of the slipout area showing the location of the drains; Figure 8 is a typical cross-section through the slipout. After the drains were installed the embankment was restored and the pavement built up to the original grade. There has been no subsequent slide movement.

Importance of Surface Drainage.

In connection with drainage of slipouts and other slides, attention is called to the importance of surface drainage as well as subdrainage. Every precaution should be taken to prevent saturation of the slide mass by surface runoff. Surface ditches should be constructed above the slide when necessary, to intercept storm run-off; slopes should be reshaped, and benches or ditches constructed to carry off surface water as rapidly as possible. Paving of surface ditches may be required to prevent percolation of surface water into the slide material. Surface water should be diverted from the slide area in a separate drainage system, rather than being allowed to enter the subdrains.

Use of Strut or Counterweight Fill.

Although subdrainage of some type is the corrective treatment most frequently applied to roadway slipouts, an entirely different method has been used successfully where the terrain is suitable--namely, the use of a strut or counterweight fill. In the circular arc failure of a slump type slide, the soil at the toe tends to move outward and upward; the application of a surcharge weight at the proper location adds to the forces resisting slide movement, and will tend to stabilize the slide. This principle is often applied to the design of embankments over unstable foundation soil, by placing toe support fills outside the normal slope lines. If the toe of a slipout is on level terrain, or if there is a stable bank or stable ascending slope just outside the toe of the slipout, then the construction of a strut fill may provide sufficient added resistance to produce stability. However, the slide must be carefully analyzed to assure that the toe support fill will not in itself be unstable, and that the added fill weight is placed where it will be most effective.

Correction by Combination of Methods.

About a year after completion of one of the California Freeways a roadway slipout caused loss of one traffic lane and jeopardized the remaining lanes. Because of the heavy volume of traffic it was imperative that the slipout be corrected before the movement of traffic was seriously impaired, and with minimum interference to traffic. After borings were made to determine the depth of the slide and to locate groundwater, the corrective treatment was designed. A transverse stabilization trench was excavated along the axis of the slide, a drainage trench was constructed along the toe of the slipout, horizontal drains were installed, and a toe support fill constructed at the toe. Figure 9 is a plan of this slipout showing corrective treatment, and Figure 10 shows a typical cross-section through the slipout. This is an example of a slipout corrected by a combination of three of the methods mentioned above, namely, stabilization trenches, horizontal drains and strut fills. It is cited as an illustration of special treatment designed for a particular set of conditions.

Summary

Correction of landslides and slipouts has been a major problem in California highway construction and maintenance. Numerous methods of correction have been applied. The corrective treatment is determined for each particular location after exploration and analysis of the slide. Some of the major types of slides and the most common methods which have been used successfully in their correction on California highways are as follows:

Rock Slides.

Correction is usually by flattening of cut slopes, often in conjunction with unloading of the slide and construction of benches.

Slump Slides (other than roadway slipouts).

The methods used in California for correction of slump type landslides include: (1) drainage by installation of horizontal drains; (2) unloading the slides, usually by flattening slopes and constructing benches; (3) construction of retaining walls or bulkheads at the toe of the slide. A combination of the first two methods is often used.

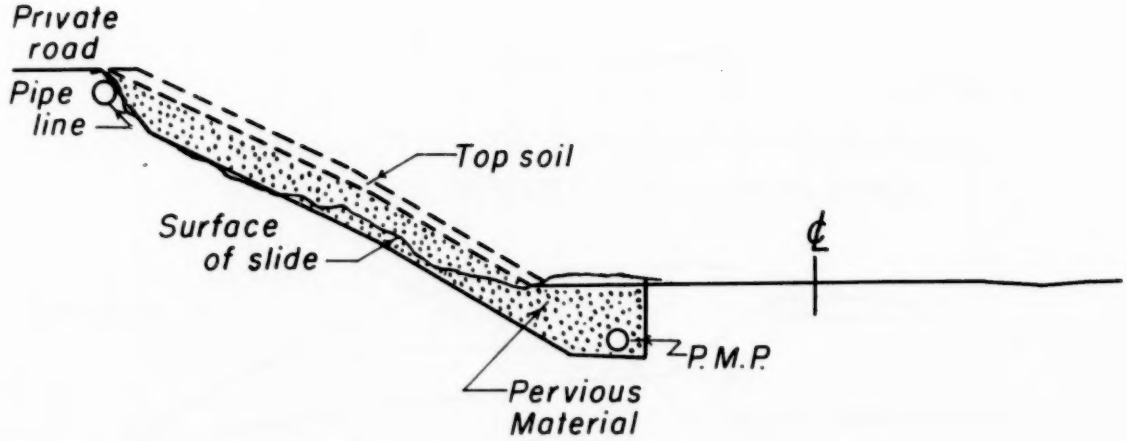
Roadway Slipouts.

Three of the methods which have been used effectively for correction of roadway slipouts are: (1) installation of horizontal drains; (2) construction of stabilization trenches; (3) placement of toe support or strut fills.

In conclusion, two points should be emphasized; first, there is no simple universal method of correcting all landslides; each slide must be studied thoroughly and the most economical treatment designed for that particular slide; second, it is much easier and cheaper to prevent a landslide than to correct it. Too often, thousands or tens of thousands of dollars are expended in correction of a landslide or slipout which could have been prevented by relatively inexpensive preventive treatment during constructuon.

Acknowledgment

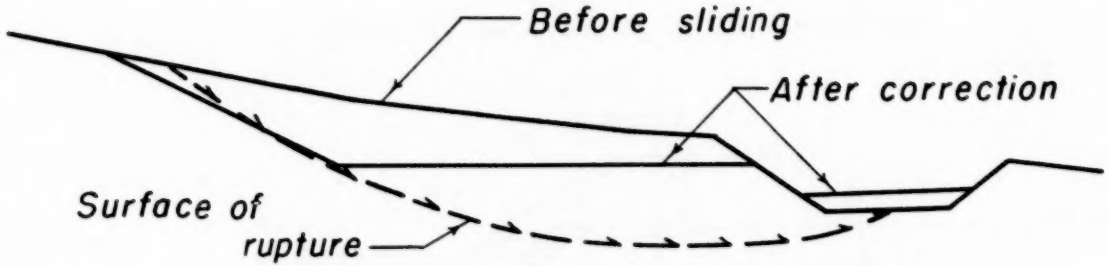
The material for the illustrative examples in this paper was obtained from the files of the Materials and Research Department of the Division of Highways. The writer is indebted to T. W. Smith for assistance in compiling these data, and to H. R. Cedergren for constructive comments on presentation.



Typical section of slide treament by pervious blanket & underdrain.

Scale 0 10

Figure. 1



Typical cross section of slide.
Correction by benching and strut fill.

Figure. 2

Scale 0 50

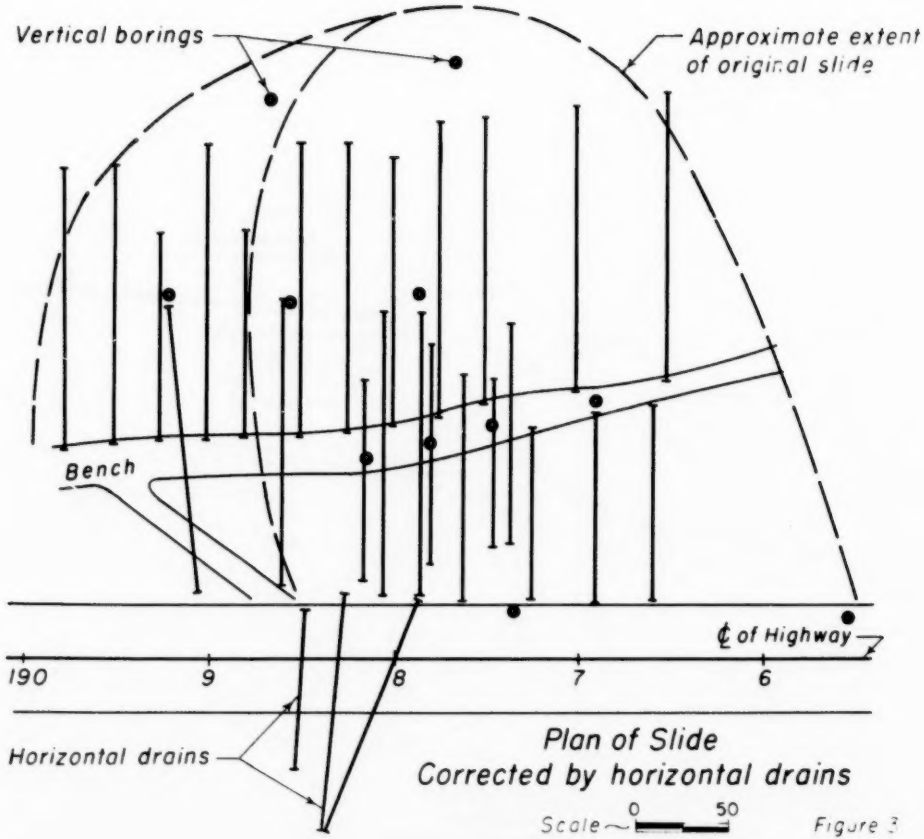
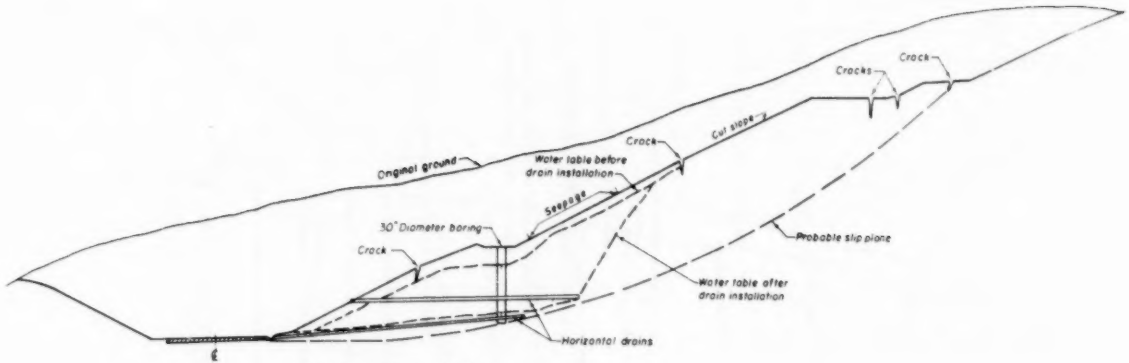
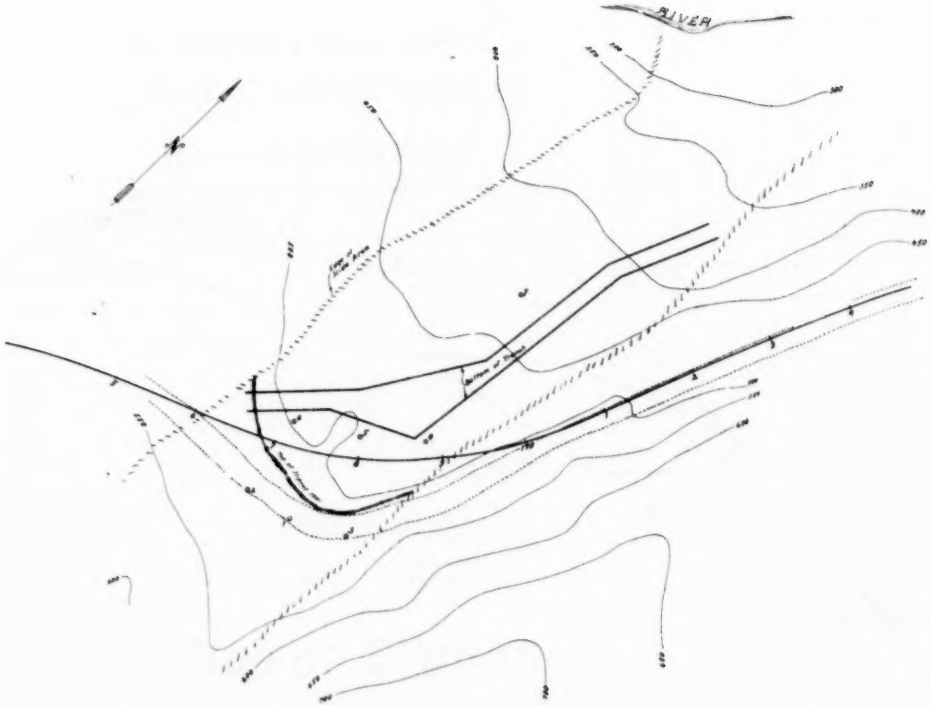

Vertical borings
Approximate extent of original slide
Bench
℄ of Highway
190
9
8
7
6
Horizontal drains
Plan of Slide
Corrected by horizontal drains
Scale 0 50

Figure 3



Typical cross section of slide with horizontal drains

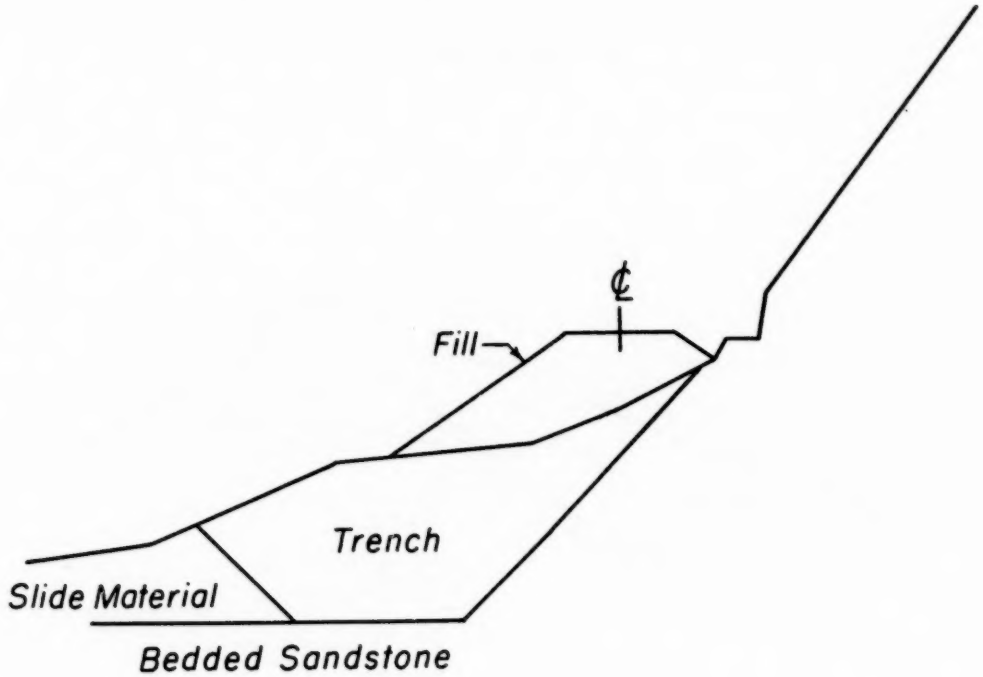
Figure 4



Plan of Slipout
Corrected by Stabilization Trenches

Scale 0 50

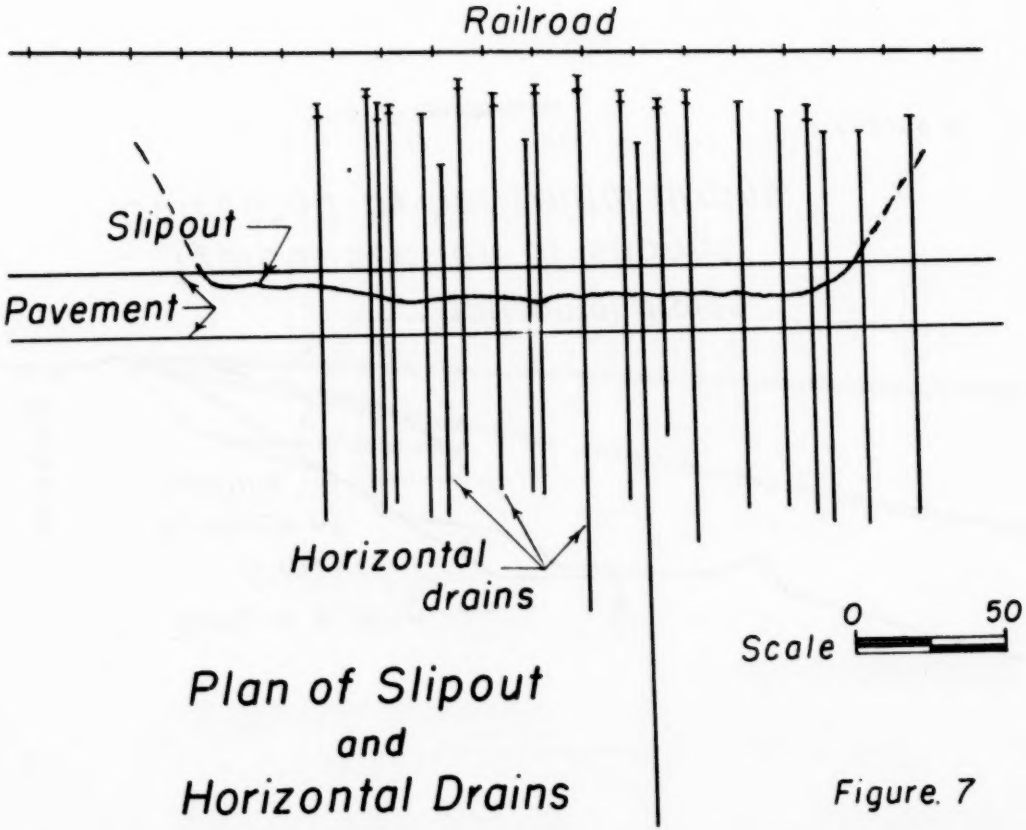
Figure 5



Typical cross section
of slipout with trench

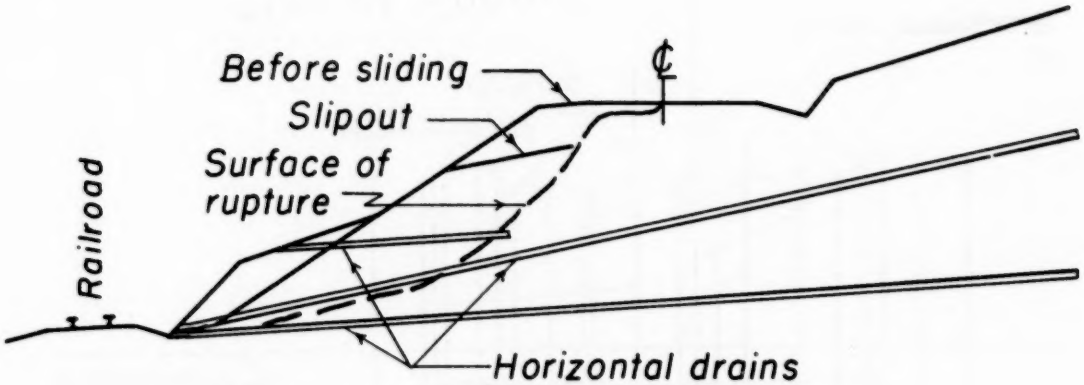
Scale 0 40

Figure. 6



Plan of Slipout and Horizontal Drains

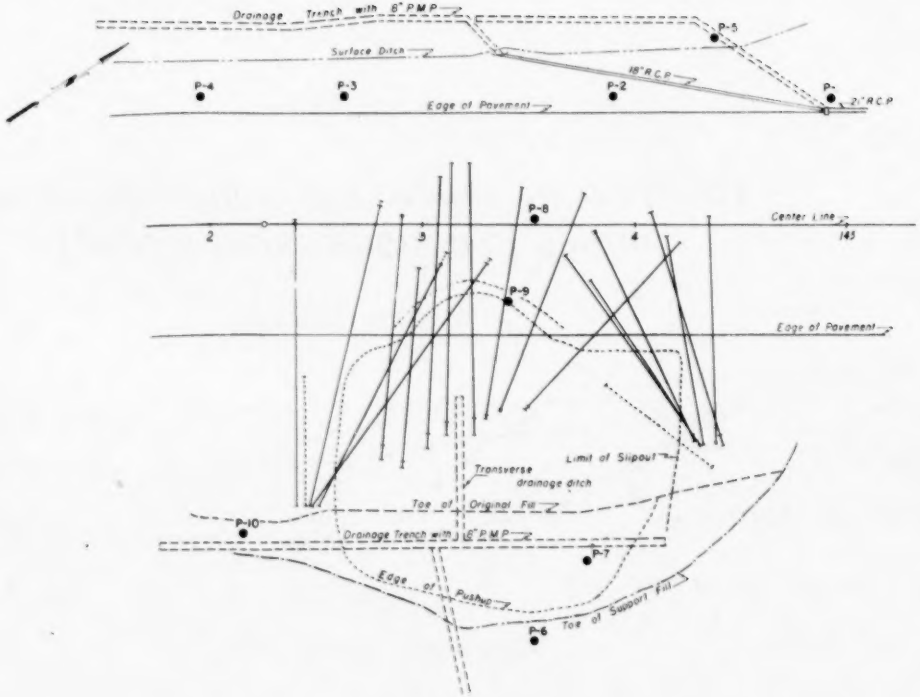
Figure. 7



Typical section of slipout.
Corrected by horizontal drains.

Scale 0 20

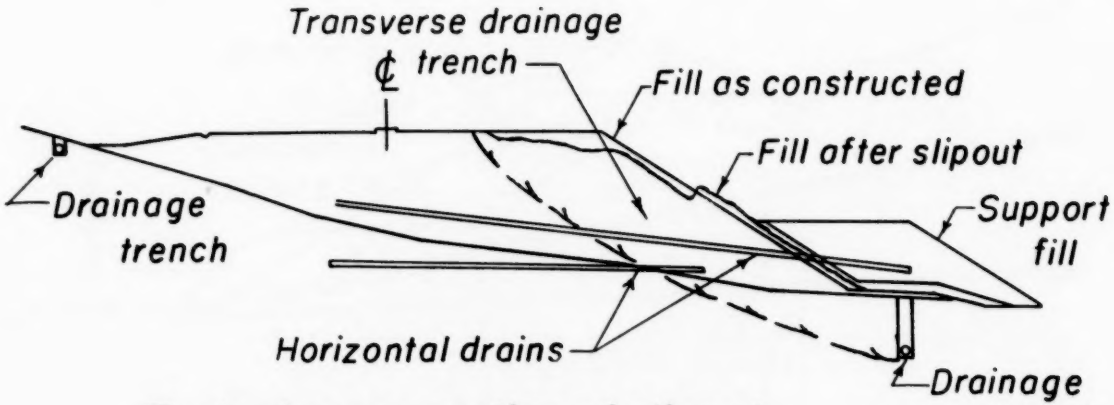
Figure. 8



Plan of Slipout
with combination of corrective methods

Scale 0 20

Figure 9



Typical cross section of slipout
with combination of corrective methods

Scale 0 40

Figure. 10